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A methodology for comparing the variable costs of the continuous and periodic review models.

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THESIS

A METHODOLOGY FOR COMPARING
THE VARIABLE COSTS OF THE
CONTINUOUS AND PERIODIC REVIEW MODELS

by

Christopher D. Knaggs

March 1984

Thesis Advisor: A. W. McMasters

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A Methodology for Comparing the Variable Costs of the Continuous and Periodic Review Models

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ABSTRACT

The optimal use of the continuous review model requires that an inventory system be examined after the receipt of every demand. Sometimes a delay can be encountered in the timing of these reviews due to several uncontrollable factors. As the length of these delays increases, a point is reached where it is better to switch the inventory system to a periodic review model. This thesis develops a methodology by which this point can be found for varying cost factors and demand levels. Using simulation, an example series of curves is presented that demonstrates the optimal point to switch inventory models for selected lead times. If delays are expected in the time between reviews, using the methodology offered in this paper will provide the manager an informational criterion for deciding what inventory model to use in a stocking system.

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I. INTRODUCTION

A. BACKGROUND

Traditional inventory systems revolve around two basic models. These models are the continuous review model, often called the Q-model, and the fixed period review model, often referred to as the P-model. Most large inventory systems use one of the two aforementioned models, in full or in part, to control inventories while minimizing the variable order and holding costs while also maintaining some minimum level of service.

The continuous review model is so named because inventory levels are reviewed every time an item is demanded. This model allows a manager to be more aware of a potential out-of-stock condition, but it can require a costly review system. In a fixed period review model inventory levels are checked only after a set period of time has elapsed. The total yearly costs of inventory review is less than what would be required for the Q-system, but large variances in demand could cause additional stock-outs if the time between reviews is extensive.

With the advent of the computer more and more activities use the continuous review model [Ref. 1]. They feel that the additional responsiveness in the Q-model compensates them (in reduced stock-outs) for the more expensive review system.

This trade-off between the implicit costs of a stock-out and the actual costs of the review can be easily represented, and quantified, with optimal cost formulas theoretically determined for each model. However, few systems are operated in a totally optimal manner. Most organizations find themselves constrained by uncontrollable variables and conflicting objectives that require their inventory systems to be operated in a less than optimal fashion. Each one of these additional constraints exacts a cost that must be calculated in order to determine the true total costs of operating an inventory system. The purpose of this thesis is to examine one of these non-optimal inventory systems and show, through simulation, what additional costs result when the system is not operated in a totally optimal manner.

The United States Navy uses a continuous review system at their Inventory Control Points (ICP). Theoretically, the inventory level of each stocked item is checked upon every issue. If an item is below a pre-determined reorder point a requisition is generated to the appropriate procurement activity which, at some later date, will bring the inventory back up above the reorder point [Ref. 2]. Many times, however, an individual item's inventory is not examined when there has been demand activity. Several factors can cause delays in these examinations. Some of these factors are computer downtime, delays in funding, or inadequate personnel resources to do the reviews. When delays occur between

receipt of a demand and a check of the relevant inventory level the continuous review system is not being operated optimally and a cost is being incurred by the Navy.

B. PURPOSE

This thesis examines the costs of running a continuous review model non-optimally by suing simulation to create an inventory system similar to the Navy's. The first simulation is configured to show both the theoretical optimal (lowest cost) inventory system, and various derivations where there are fixed period of review imposed on the continuous review model. Since it is possible that the period between reviews could extend long enough in the Q-model that the fixed period review model would become more applicable to a given situation, a second simulation model was developed. That model imitates what a Navy inventory system would be like if a P-model was employed at the Inventory Control Points for specific items. The use of these two simulations gives us the ability to compare and contrast the Q and P models in order to determine which model is best for any given item and period of review. In the next chapter, the specific make-up of each one of these models is outlined and an analysis is completed on the mathematical differences between the Q and P system as well as the inherent advantages and disadvantages of each model. Chapter III describes what assumptions were used in the development of the simulations.

Appendices A and B present the programs used to make the simulation runs.

The last three chapters provide an analysis of the types of information available from the simulations. Chapter IV details a methodology for constructing a curve comparison between the two models using the simulation programs. The following chapter then takes select data from these curves and presents an analysis of trends, optimal model costs, and costs to do a review. The last chapter contains a summary of the thesis along with conclusions and recommendations.

II. MODEL REVIEW

A. INTRODUCTION

In general, inventory theory concerns itself with two models--the continuous review model (Q-model) and the fixed period review model (P-model). These two models can be considered under either assumptions of deterministic or stochastic demand. Since the purpose of this thesis is to simulate, as close as possible, an actual inventory system, the version having stochastic demand will be used. The associated mathematical theory and imputed optimal cost calculations for each model are outlined in the sections below.

B. CONTINUOUS REVIEW MODEL

The basic element common to continuous review models is that the state of the supply system is known at any instant of time and, therefore, decisions may be made at the instant that an inventory position (on-hand inventory plus on-order minus backorders) falls to some reorder level. In the Q-model an optimal quantity Q, based on the Wilson Economic Order Quantity (EOQ), is assumed to be ordered whenever the inventory position falls to a reorder level (r). Thus the inventory position is raised to $Q + r$ immediately following the order [Ref. 3].

When working with the stochastic Q-model, the inventory can be divided into working stock and safety stock. Working stock is what is expected to be used during a given time period. The average working stock is one-half the optimal order quantity. Safety stock does not depend on the optimal order quantity. It is based on the variability of the stochastic demand distribution and is used to protect against higher than expected demand levels.

Each unit of increase in safety stock provides a deminishing benefit. The first unit of inventory above the expected demand provides the largest marginal increment of protection against running out of stock. As additional units of safety stock are added this marginal protection gradually decreases until the cost of storing additional units plus the expected stock-out cost is at a minimum. This level is defined to be the optimal safety stock level and movement away from this result produces an increase in variable costs [Ref. 4].

In continuous review models the reorder point is composed of a mean leadtime demand (the time between placing an order and when the order arrives) plus the safety stock. Throughout this thesis the mean leadtime demand will be specified and a Poisson distribution will be assumed for the random demand [Ref. 5]. The Poisson probability distribution was selected over a normal probability distribution because; (1) it more accurately represents items with low demand

(less than 20/year), (2) at higher demand levels the Poisson approximates the normal even though some round-off problems can occur, and (3) the Poisson avoids the possibility of a negative demand.

The actual determination of the optimal order quantity (Q) and reorder point (r) requries an iterative approach because of the discrete demand distribution. The optimal values are the largest Q such that [Ref. 6]:

$$Q(Q-1) \leq \frac{2\lambda\ [A + \pi\bar{n}(r)]}{IC}$$

and the largest r such that:

$$H(r) > \frac{QIC}{QIC + \pi\lambda}$$

where:

π = stock-out cost per unit short

r = reorder point

A = order cost per order

C = purchase price of one unit

IC = holding cost per unit

Q = optimal order quantity

λ = expected annual demand

H(r) = the probability of a stock-out during a procurement lead time when r is the reorder point

$\bar{n}(r)$ = expected number of stock-outs per order cycle

The steps of the approach are:

1) Find largest Q such that: $Q(Q-1) < \frac{2\lambda A}{IC}$

2) With that Q determine: $RISK = \frac{QIC}{QIC + \pi\lambda}$

Using this RISK value determine the largest value of r such that:

$$CCDF = \sum_{x=r}^{\alpha} p(x) > RISK$$

where p(x) is the probability of a demand of x during procurement lead time.

A Poisson distribution table is needed because of the iterative process. When this table is generated (using the applicable mean lead time demand) it is necessary to establish the complementary cumulative distribution (CCDF) of the distribution. Appendix III is a program that will compute the Poisson CCDF using different mean leadtimes.

3) Using the above r, and the CCDF Poisson distribution table find: [Ref. 5]

$$\overline{n}(r) = (\overline{M} * CCDF(r-1)) - (r * CCDF(r))$$

4) With this value of n(r) we determine the largest Q such that:

$$Q(Q-1) \leq \frac{2\lambda\ [A + \pi\bar{n}(r)]}{IC}$$

5) Returning to step 2 with this value of Q, the steps are repeated until such time that the r does not change with the next iteration. The resulting Q and r are optimal and the safety stock can be computed by subtracting the expected mean lead time demand ($\bar{M}$) from r.

6) Compute the expected annual holding cost:

$$\text{holding cost} = IC\ [\frac{Q}{2} + (r - \bar{M}) + \bar{n}(r)]$$

7) Compute the expected annual order cost:

$$\text{order cost} = \frac{\lambda A}{Q}$$

8) Determine the expected annual stock-out costs:

$$\text{stock-out cost} = \frac{\lambda}{Q}\ \pi\ \bar{n}(r)$$

9) Add up the order, holding, and stock-out costs from steps 6, 7, and 8 to get total variable costs.

$$TVC = \frac{\lambda A}{Q} + IC[\frac{Q}{2} + (r - \bar{M}) + \bar{n}(r)] + \frac{\lambda}{Q}\ \pi\ \bar{n}(r)$$

The above total optimal cost information will provide the baseline costs by which comparisons will be made when changes are introduced into the simulation.

Since the purpose of this thesis is to compare the P-model with the Q-model (constrained to operate as the P-model), the costs of doing the review must be considered. It is the product of the expected annual demand λ and the cost (RC) of an individual review.

$$\text{Review cost} = \lambda RC$$

However, review costs need not be considered as a direct part of the total variable cost equation in the analysis in Chapter IV . Their effect will be analyzed in Chapter V.

The Q-model is more expensive to administer than the P-model. A perpetual and continuous inventory record must be maintained which often requires computer support for a large number of product items. However, this perpetual inventory system is the most demand responsive and this characteristic becomes even more important as demand variation increases [Ref. 7]. The Q-model also has a lower average inventory level because less safety stock is required than the P-model. An additional advantage of the continuous review model is that it keeps management in close touch with changing demand patterns which aide in production planning as well as in inventory management.

C. FIXED PERIOD REVIEW MODEL

Time based inventory models are most appropriate when an organization is faced with fairly uniform independent demand and wants to maintain an inventory most of the time. When demand is continuous time and quantity can be considered interchangeable [Ref. 4].

For the fixed period review model we need to calculate two variables--the time between reviews (T) and the maximum inventory level (E). Only after the time T has passed will inventory levels be checked and an order placed. The size of the order will be the difference between the maximum inventory level for each item and the inventory position at the time of the review. Unlike the Q-model where the order quantity is constant, the order quantity for the P-model will vary depending on fluctuations in demand between orders.

The maximum inventory (E) will consist of the safety stock plus the average demand during an order interval and lead time. In the fixed order interval system safety stock is needed for both the order lead time (M) and order interval (T) [Ref. 4].

The Poisson distribution is also used in the fixed period review model to simulate random demand. However, the mean of the distribution represents demand both during the order cycle and lead time.

The steps for finding the optimal (T) and (E) also require an iterative solution similar to that of the continuous review model. The following is the solution procedure for the P-model [Ref. 6]:

1) Establish the initial time between reviews:

$$T = \sqrt{\frac{2A}{IC\lambda}}$$

2) and calculate the probability of a stock-out:

$$RISK = \frac{TIC}{TIC + \pi}$$

where:

π	= stock-out cost per unit
A	= order cost per order
E	= maximum inventory level
IC	= holding cost per unit
$\overline{M}$	= mean demand in an order lead time
$\overline{n}(r)$	= expected number of stock-outs per cycle
C	= price per unit
λ	= annual demand
RC	= review cost per review
T	= review period in years
D	= mean demand in an order cycle

3) Calculate order cost = $\frac{A}{T}$

4) Calculate the maximum inventory level using the initially determined probability of a stock-out H(r). If this is a new iteration, compute a new H(r) based on the changed T value from step six.

Consulting a Poisson CCDF for a mean demand in a lead time and an order cycle ($\bar{M}$ + D), find the E value corresponding to the point where the complementary cumulative of the distribution (CCDF) is just greater than the RISK. This E value will be used to compute the rest of the cost functions.

$$H(r) = \sum_{x=r}^{\alpha} p(s) > RISK$$

5) Find the expected number of stockouts per cycle from:

$$\bar{n}(r) = ((\bar{M} + D) * CCDF(E-1)) - (E * CCDF(E))$$

6) Compute the expected annual holding cost using the generated E from step two:

$$\text{holding cost} = IC\ [E - \frac{\lambda T}{2} + \lambda \bar{M}]$$

7) Determine the expected annual stock-out costs:

$$\text{stock-out cost} = \frac{\pi}{T}\ \bar{n}(r)$$

8) Add up the order, holding, and stock-out costs from step 3, 6, and 7 to get the total variable costs.

$$TVC = \frac{A}{T} + IC\,[E - \frac{\lambda T}{2} + \lambda\overline{M}] + \frac{\pi}{T}\,\overline{n}(r)$$

Returning to step 3, a different T is chosen in order to calculate a new probability of stock-out. The T to be chosen will vary with each iteration as changes in total variable costs are observed. Finally, the correct maximum inventory level E and time between reviews T will be obtained when the iterations no longer result in a lower total variable cost.

Since the purpose of this thesis is to compare the P-model with the Q-model (constrained to operate as the P-model) the costs of doing the review must be considered eventually. For the P-model the annual review costs are:

$$\text{Review cost} = \frac{\lambda}{Q}\ RC$$

The total optimal costs calculated provide a baseline by which these costs can be compared with similar costs generated in the Q-model when that model is constrained to operate as the P-model.

The major difficulty with the fixed order period model is the system's limited responsiveness to a rapidly changing demand. Management has only limited knowledge, if any, of demand changes until the review period is reached and

shortages are more likely to result. Review costs are lower by having inventory examined at periodic intervals, but there is less information flow and control over inventory with this model than with the Q-model.

III. THE SIMULATIONS

A. BACKGROUND

The simulations for the continuous review and fixed period models were developed to accurately represent the operation of an actual inventory system. Even though there are significant differences between the Q and P models, the major part of the simulations are common to both models. This chapter will describe the operation and assumptions of the simulations. The actual programs for the simulations are included as Appendix A and B.

As mentioned in Chapter II, the Poisson distribution is used to generate demand. It is assumed that requisitions come in one at a time for a total quantity of one. A subroutine randomly generates the elapsed time between requisition arrivals (in days) based upon a mean expected daily demand. The times between arrivals are accumulated to provide a record of the total time of the simulation and how much time has passed since the last review.

The time between reviews is used similarly in both models, but the time is input in different ways. In the continuous review model the time between reviews is read in from a data file so that this time can be altered to represent a fixed period constraint. The initial review time is always set at zero so that the system will be reviewed upon the receipt of

every requisition. This allows a comparison to be made between the theoretical optimal total cost--and the total cost of the simulation when the continuous review model is being operated in an optimal way. This check insures that the simulation is accurately representing the system. Succeeding times between reviews are then input based on how many days away from the optimal that the system is desired to be deviated.

B. COMPUTATIONS

The fixed period model's initial time between reviews is calculated based on the initializing formulas outlined in Chapter II. This first review time will not necessarily represent the optimal time between reviews for the system. The optimal review time is computed using the iterative procedure described in Chapter II. This optimal review time is input by the use of a predetermined percentage factor that sets the optimal time between reviews into the program. This percentage factor also allows the simulation of the P-model to be deviated away from the optimal for the purpose of examining alternative methods of operating the fixed period review system.

The ability to vary the time between reviews is important because it is the basic way by which the two models can be compared. For example, the simulation can find the optimal

time between reviews in the P-model, and then fix that time into the Q-model. The resulting costs of both models can then be compared and analyzed.

The key parameters in both models can also be altered in order to analyze different types of inventory items. A most important factor, mean annual demand, can be changed by using different values for the mean time between arrivals in the Poisson process (RLAM). For example, a time between arrivals of 0.5 (in days) would generate a mean number of 2 requisitions a day or 740 a year. A time between arrivals of 8.0 would cause a mean demand volume of about 45 per year. As the time between arrivals increases, and hence decreases the yearly mean demand, the variability of the Poisson process will also become more apparent. Other parameters such as holding, order, and shortage cost can also be changed.

Reorders are generated differently by the models, but order quantities for the two systems are both based on inventory position. Inventory position is defined as a combination of the on-hand inventory level plus currently on-order minus any backorders. The continuous review system will create a reorder when both the time between reviews has elapsed and the inventory position has fallen below the reorder point. The Q-model, when operated in a periodic review mode, has as a reorder quantity the difference between the maximum inventory position (sum of the reorder point and economic order quantity) and the current inventory position.

This order policy corresponds to what actually happens in the Navy's wholesale inventory system if the breach of a reorder point is not detected immediately due to some review time delay. Operating the system this way prevents the problem of inventory levels becoming negative and never rising above the reorder point again. A reorder in the fixed period review model is generated when the time between reviews has elapsed and the inventory position is less than the maximum established inventory level.

Two subroutines are used to generate orders, keep track of when the orders are due to come in, and add to the on-hand inventory the appropriate quantity when an order has arrived. A constant lead time, which can be varied on different runs, is input at the beginning of the program. Any number of orders can be outstanding at a time. The time ramaining until each order will arrive is decreased, as days pass, until there is a simulated receipt.

Theoretical costs for each simulation are computed as discussed in Chapter II. These theoretical costs are compared with the costs actually resulting from running the simulation. Simulation costs result strictly from what actually happens when the program is run under the inputed constraints and variables. For example, if five orders per year are generated then the total order cost will be five times the appropriate cost to order.

IV. COMPARISON OF CURVES

A. BACKGROUND

As originally stated, the purpose of this thesis is to find the "crossover" point in an inventory system which it is advantageous to shift from a continuous review model to a periodic review model. The simulations, as outlined in Chapter III, provide the mechanism for finding this point by being able to run both the Q and P models under similar conditions so that a comparison of the resulting total variable cost curves can be made. This chapter describes the details of the methodology by which these "crossover" points are found.

There are a infinite number of possible combinations of holding, shortage, and order cost that could be used in the simulations. Similarly, it is possible to go through endless variations of item price, lead time, and demand volume. As a demonstration of the type of information that is desired from the simulations, an example follows in this chapter which will limit itself to one particular inventory item. The variable factors and costs that comprise this one inventory item are as follows:

Item price:	$300.00
Holding rate percentage:	.23 per dollar per year
Order cost:	$175.00 per order
Shortage cost:	$350.00 per unit/year

The above parameters will remain constant throughout all simulation runs. The only parameter that will be varied is the yearly number of requisitions (annual demand volume). A second parameter, lead time (in days), will also be varied but in a limited way. Three lead times will provide a sufficient number of curves to demonstrate the effects of a varying lead time on the crossover points of the two models. At this point the cost to do the review is ignored. Review cost impact on these curves will be analyzed in the next chapter.

B. CURVE CONSTRUCTION

It was necessary to run each simulation a number of times to get an average of the total annual variable costs for both models. In order to provide this "averaging" a minimum of ten simulation runs were made with all factors held constant. If these runs showed low variability in the resulting cost data no further simulations were conducted. If high variability was encountered more simulations were run until a good consistent average of costs could be obtained. Furthermore, to provide an opportunity for the programs to produce an average of costs over a long period of time, the total length of each simulation run was fifty years.

After examining data for several Navy managed inventory items it was observed that a rough average lead time for most stock numbers was in the range of five to seven quarters.

For this reason the first set of simulation runs used a lead time of 550 days. With this "set" lead time demand was selectively varied from two requisitions per year to one-hundred requisitions per year.

Figure 1 is an example of the crossover point. Figure 1 is for a demand rate of twenty-five requisitions per year and shows the Q-model starting from its optimal total variable cost--the point where the inventory system is reviewed every day. As the Q-model is constrained to only review the system on a gradually increasing time basis, the total variable cost begins to increase. This increase in costs is primarily due to the higher number of stock-outs that are incurred because they are not detected until a review is made. Initially, the rise in costs are gradual, but as more and more days elapse between observations of inventory levels the costs rise at an increasing rate.

In the P-model the costs of having a daily review are very high. This is due to the assumption that an item is consistently ordered up to a maximum inventory level every time the inventory falls below that specified level. Slowly, as the time between reviews increases, annual order costs go down until some optimal point where the total annual variable costs of the P-model are at a minimum. Even though order costs continue to decrease after this minimum, the further delay in reviews causes an increase in stock-out

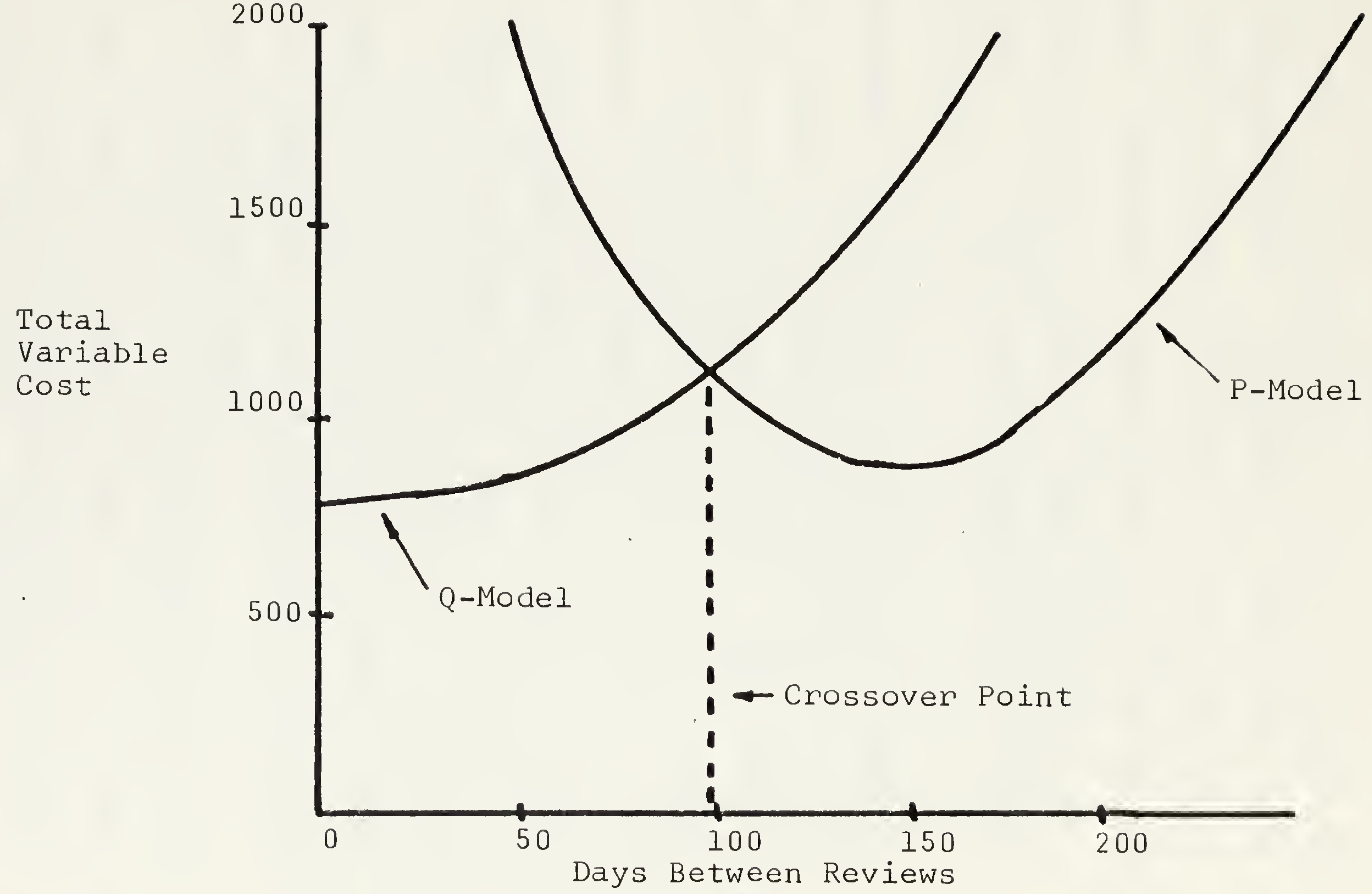

Figure 1 Crossover Point - Demand 25/Year

costs. This increase in stock-out costs eventually outweighs the savings in order costs.

The place where the variable cost curves intersect is termed the crossover point. In Figure 1 this point is a time between review periods of 99 days. If a inventory manager, using a continuous review system, allows the time between reviews to extend beyond 99 days then he/she is better off going to a fixed period review model to obtain a lower total variable cost.

It is important to note that any time one of these models is not operated at its minimal cost point a penalty is being incurred by the inventory system. Even though the periodic review model in Figure 1 does not become preferred over the continuous review model until after 99 days, the continuous review system still is being operated non-optimally unless the system is reviewed every day. Conversely, for the P-model, using a time between reviews that is different from the bottom of the total variable cost curve at 160 days will result in a higher cost for the system--even though it is cheaper than using the Q-model.

Figure 2 presents a set of crossover points for a lead time of 550 days and six different demand rates including that of Figure 1. It is easy to see that the crossover point decreases with increasing yearly demand volume.

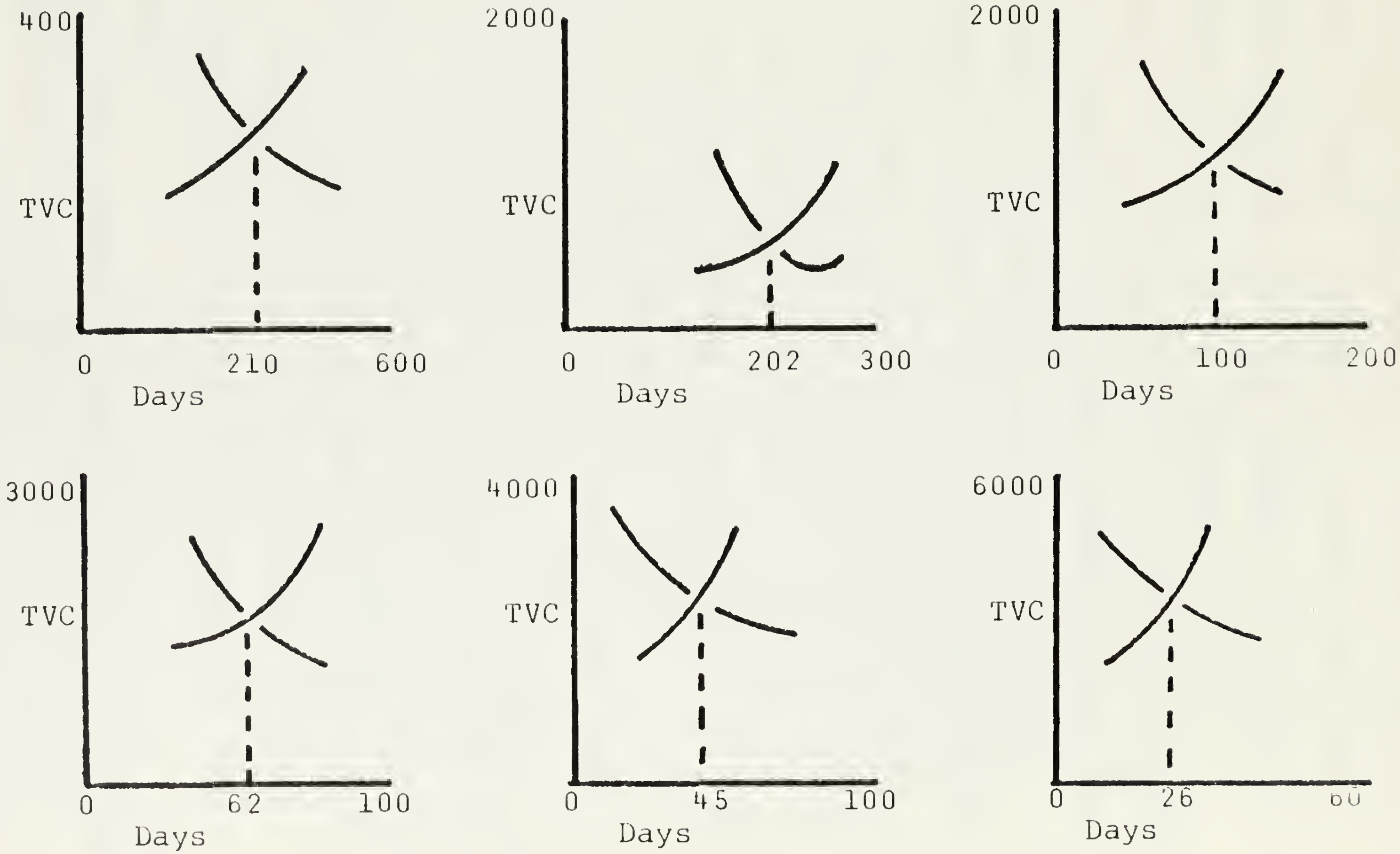

Figure 2 Crossover Points For Varying Demand

From data such as provided by Figure 2 it is possible to construct a plot of crossover point times as a function of the mean annual demand. Figure 3 is such a plot for the information from Figure 2. For example, if demand is fifty requisitions per year it is favorable to switch inventory models if the time between inventory reviews slips beyond 62 days. Similarly, a low mean demand of only five per year would have a crossover point of over 202 days.

Finally, other simulations were run in the same manner as outlined in this chapter but with changing lead times. One set of simulations was run with a lead time of three quarters (275 days) and another set with a lead time of nine quarters (825 days). Figure 4 presents these two new curves as well as the original curve of Figure 3.

Figure 4 shows that as lead times decrease the total number of days to the crossover increases. For example, at a demand rate of fifty per year a lead time of 825 days has a crossover of 85 days, a lead time of 550 days has one of 62 days, and a lead time of 275 days has one of 24 days. These results are quite logical since missing a reorder point would be expected to be more devastating in a long lead time situation.

This chapter has presented a methodology for establishing the exact point that it is preferable to change inventory systems from continuous review to periodic review. It has

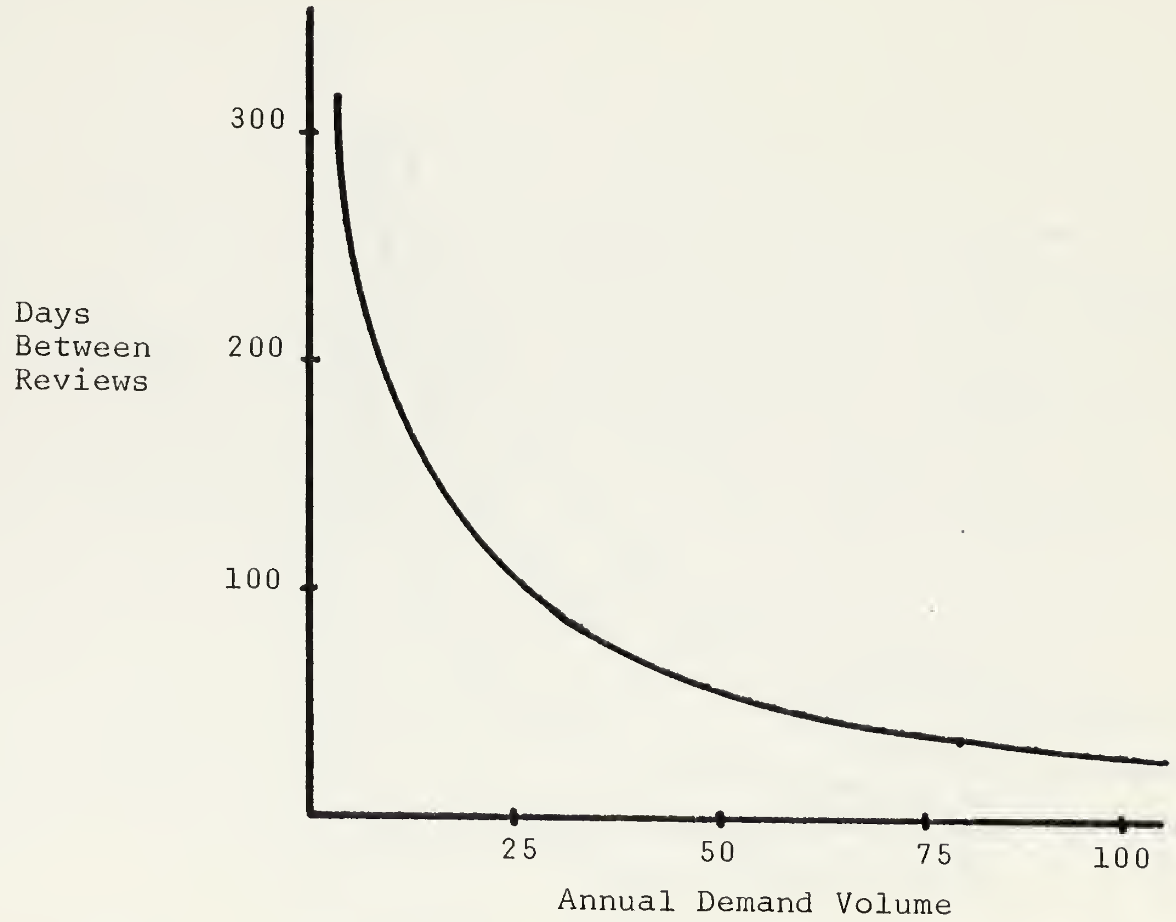

Figure 3 Q-Model To P-Model Crossover

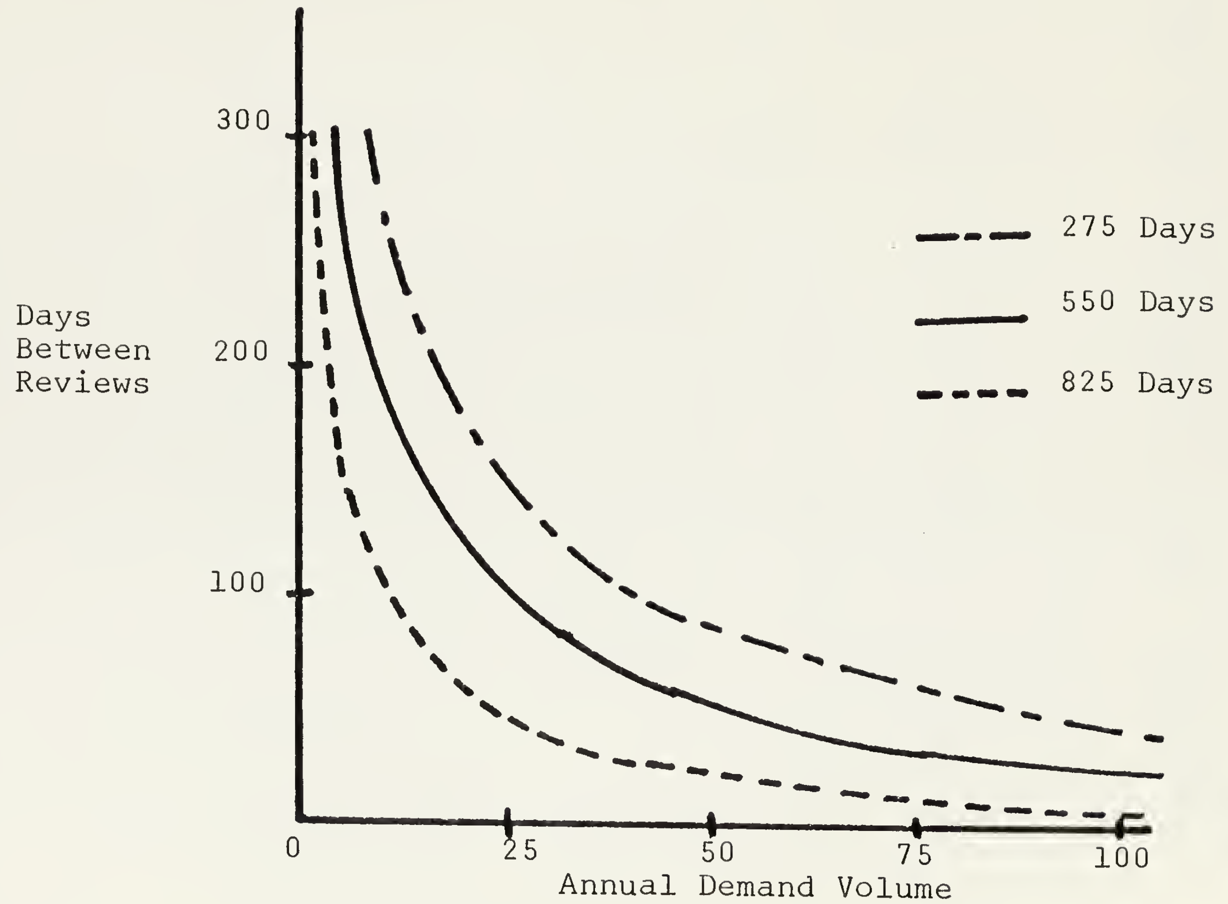

Figure 4 Q-Model To P-Model Crossover Multiple Lead Times

highlighted only one particular set of item cost data. However, this method does provide a potential way for an inventroy manager to decide if a change in inventory models is necessary if he/she finds themselves unable to review inventory levels upon the receipt of every requisition.

V. COST ANALYSIS

A. INTRODUCTION

As stated in Chapter IV, the simulation runs were limited to one inventory item. As such, any generalizations about variable cost behavior would only apply to inventory items with relatively similar cost parameters. However, there were trends observed with possible applicability over an entire inventory range.

B. OPTIMAL MODEL COSTS

In all cases the optimal total variable cost of the continuous review model (Qopt) was lower than the optimal variable cost of the periodic review model (Popt). Table I (columns 2 and 3) list these optimal costs in lead time categories by varying demand rates. The differences between these optimal costs (Col. 4) varied from 2 to 41% with the largest differences being experienced in the lower demand rates. The reasons for this trend is that P-model order costs, as a percentage of optimal total variable costs, increases as demand decreases. The Q-model order cost percentage remains relatively stable as demand changes. This causes the percentage difference in total variable costs for the two models to increase as demand falls. In addition, as lead time decreased the average differences between Qopt and

TABLE I

LEAD TIME AND DEMAND VARIABLE COST COMPARISONS

LEAD TIME = 275 DAYS

(1) Mean Demand Rate	(2) Optimal Q-Model TVC	(3) Optimal P-Model TVC	(4) % Diff Columns (3-2)/3	(5) Cross-Over Point	(6) Cross-Over TVC	(7) Equality Review Cost
100	$2119	$2161	2%	31	$3810	$0.42
75	1678	1711	2	52	2406	0.45
50	1548	1578	3	75	1698	0.60
25	868	911	5	128	1011	1.72
5	337	390	16	252	410	10.60
2	180	236	31	361	201	28.00

LEAD TIME = 550 DAYS

100	$2171	$2236	3%	26	$3902	$0.65
75	1778	1831	3	45	2598	0.70
50	1645	1710	4	62	1927	1.30
25	900	943	6	99	1160	1.72
5	421	500	19	202	450	15.80
2	196	268	37	310	210	36.00

LEAD TIME = 825 DAYS

100	$2422	$2518	4%	13	$4210	$0.96
75	2075	2158	4	22	3798	1.10
50	1762	1850	5	33	2804	1.76
25	1125	1203	7	48	1701	3.12
5	537	660	23	150	497	24.60
2	202	284	41	251	103	41.00

Popt consistently increased. The data indicated a linear relationship showing a 1.1% decrease in optimal cost differences for every 100 day increase in lead time days.

C. CROSSOVER POINT COSTS

Given constnat lead times the crossover point of the two models always increased as demand rates decreased. These periods between reviews were quite large, sometimes extending out to a year, for items with low demand. Conversely, highly demanded items experienced crossover points as short as 13 days. This information is listed in column 5 of Table I and was used to plot Figure 4.

The fact that a point exists where switching from a Q-model to a P-model will always result in a cost improvement does not alleviate the problem that both models are being operated in a non-optimal fashion. Table II highlights this by showing the Q and P model variable costs as a function of the review interval for just one item with a demand rate of 25 and a lead time of 550 days. The crossover for this item is at 100 days. At this point the ratio between TVC for the Q-model and the TVC for the P-model is 1.00 and the total variable costs are both $1160. Operating the Q-model optimally at 0 days of review would generate only $901 in costs so allowing the period of review to slip to 100 days will represent a 29% increase in variable costs to the Q-model system. Similarly, the P-model finds its optimal

TABLE II

SINGLE ITEM OPTIMAL VARIABLE COST COMPARISON

DEMAND = 25 Requisitions per Year

LEAD TIME = 550 Days

(1) Days Between Reviews	(2) Q-Model TVC	(3) P-Model TVC	(4) Ratio of Popt to Q-Model TVC	(5) Ratio of Q-Model TVC to P-Model TVC
0	$ 901	$5125	1.04	5.68
10	902	3421	1.04	3.79
20	921	2702	1.02	2.93
30	963	2306	.98	2.39
40	998	1922	.94	1.92
50	1067	1663	.88	1.59
60	1090	1490	.86	1.36
70	1112	1370	.84	1.23
80	1135	1290	.82	1.13
90	1148	1198	.81	1.04
100	1165	1159	.80	1.00
110	1201	1060	.78	.88
120	1280	991	.73	.77
130	1396	950	.67	.68
140	1503	948	.62	.63
150	1600	946	.58	.59
160	1721	943	.54	.54
170	1860	960	.51	.51
180	2051	982	.46	.47
190	2290	1012	.41	.44
200	2502	1023	.37	.40

cost point at $943 (a review period of 160 days) representing a 22% loss in cost optimality at the crossover point.

Table I continues with the analysis done above by listing the total variable costs at the crossover point, in column 6, for all simulated demand and lead times. In general, the higher the demand rate the greater the difference between the costs at the crossover point and the optimal costs of either model. This is significant when considering that the items with the higher demand are also the items with the highest variable costs. Straying from model optimality, in high demand situations, causes a larger cost penalty to the system than would be experienced by a lesser demanded item in the same circumstances.

D. REVIEW COSTS

As mentioned earlier in this chapter, the optimal total variable costs of the Q-model appears to be always lower than the same cost for the P-model. However, there is a point where the increasing variable costs of the continuous review model (due to longer review periods) will be higher than the optimal variable cost of the periodic review model. In all cases this review interval was found to be much less than the crossover point. Table II demonstrates this is column 4 by comparing the ratio of changing Q-model variable costs to the constant P-model optimal cost. At a period of review of 25 days the ratio goes to 1.00 and it is there

that it is optimal from a cost standpoint to switch from the Q to the P·model. However, if this is done, the period of review will have to be 160 days, not 25 days, in order to fully benefit from the switch.

All the variable costs in Chapter IV and Tables I and II do not consider the impact of the actual costs to do the review on the two models. For the data in Table II, the P-model will only by reviewed every 160 days. The Q-model, at its optimal point, is reviewed at a minimum upon the receipt of every requisition--or an average of 25 times a year. This imposes a greater cost to the continuous review system than is being experienced by the periodic review system. If it is true that, at a certain period of review, the P-model becomes cheaper to operate than the Q-model then there is an review cost that will made the optimal costs of both models equal.

For the data in Table II the review cost that will make both models equally optimal is $1.36. This $1.36 represents 0.5% of the total cost of the example inventory item ($300). If every time a manager examines inventory levels it costs the system greater than $1.36, then it is optimal from a cost standpoint to switch to the P-model and review every 160 days. Conversely, if the review cost is less than $1.36, the Q-model is optimal with reviews done upon the receipt of every requisition.

Table I lists in column 7 the relevant review costs that will cause equal model optimality for varying demand and lead times. In general, items with demand greater than 25 had more consistent, and lower, equality review costs than very low demanded items.

The costs to do a review had no impact on the review interval at the crossover point. This is logical since, at the crossover point, both models are reviewed the equivilant number of times a year. The only change is an equal increase in total variable cost.

VI. SUMMARY AND CONCLUSIONS

A. SUMMARY

The choice of an appropriate model to use in an inventory system will depend on a number of different factors. Some of these factors are related to intrinsic costs within the model itself. An example of these factors would be the order, holding, and shortage costs that a particular activity might find applicable for the business conditions in which they operate. Other factors will also affect the choice of an inventory model. These factors include the actual size of the inventory system, the availability of personnel and computer resources, or the determination of what level of service was to be maintained. Regardless of which model is chosen there is an optimal way to operate that one inventory system.

Sometimes it becomes necessary to deviate from the optimal operation of a particular inventory model. If a computer goes down it might not be possible to check stock levels upon the receipt of every requisition as is required by the "optimal" conditions of the continuous review model. If the mean demand increases dramatically the optimal set time between reviews in the periodic review model might be too long to adequately provide customer support. As these

various conditions change, a point can be reached where it is better to completely switch inventory systems rather than to continue distorting the present system.

Two major models comprise the basis by which most inventory systems operate. These models, the continuous review model and periodic review model, were analyzed in Chapter II. The purpose of this thesis was to find the point where the variable costs of these two models, under a given set of conditions, were equal. This area of equality was termined the "crossover" and it provided a point, for which, a switch of inventory models would be applicable from an annual variable cost aspect ignoring review costs.

Simulations of each model were developed to find this crossover point. Chapter III describes the simulations and the underlying assumptions that make them work. Both simulations were built as elementary representations the United States Navy's wholesale inventory system under the conditions of the periodic and continuous review models. The programs are included as Appendices A and B.

Using a given set of cost parameters a large number of simulations were run for both models at varying mean annual demand levels. A period of review constraint was imposed within the simulations to provide the change in variable costs that results from operating the models non-optimally. Once a steady state set of costs was obtained, the total

variable costs of the continuous and periodic review models were plotted as a function of the period of review for both models. The point where these cost curves intersect was the crossover point for that selected demand level.

Using varying mean annual demand values, a series of crossover points was determined for a given set of other model parameters. The crossover point values were then plotted as a function of mean annual demand.

The affect of lead time on the crossover point was also examined. Additional plots were developed from the simulation runs by changing lead time values. Chapter IV details the process by which the various curves were created. Chapter V then analyzed cost relationships between the two models for a given set of parameters. At the optimal point the Q-model total variable costs were always lower than optimal P-model variable costs. Operating either model at the crossover point was found to be inefficient and costly--particularily for items with high demand. If review costs are imposed on each model, a dollar figure per review could be found that would equate the minimum variable costs of the continuous and periodic review models. Review costs had no impact on the review interval at the crossover point.

B. CONCLUSIONS

The decision of which inventory model is best for an activity must consider a number of variables in addition to those analyzed in this thesis. However, the procedures outlined above provide a mechanism for getting such information to the decision maker. The value of this information increases if the inventory system has to be operated non-optimally due to factors beyond the control of the inventory manager. Furthermore, if deviations from optimality do occur they must be addressed since these deviations both impose a penalty on the current system in higher variable costs and, at the same time, potentially offer opportunities for lowering costs by changing inventory systems.

C. RECOMMENDATIONS

All efforts should be made to operate inventory systems consistent with the optimality assumptions that created the inventory models. Any system constrained not to do so must be constantly analyzed to ensure that the correct inventory model is being used. A methodology, such as is presented in this thesis, should be available to the manager to assist in that decision process.

APPENDIX A

CONTINUOUS REVIEW MODEL SIMULATION PROGRAM

```
$JOB
C
C THIS PROGRAM IS A SIMULATION OF A THEORETICAL INVENTORY
C SYSTEM WHERE A CONTINUOUS REVIEW MODEL IS CONSTRAINED TO
C DIFFERENT TIMES OF FIXED PERIOD REVIEW.  THE PROGRAM IS
C WRITTEN IN THE FORTRAN PROGRAMMING LANGUAGE USING THE WATFIV
C COMPILER
C
C THE FOLLOWING IS A DESCRIPTION OF THE VARIABLES WITHIN THE
C PROGRAM.
C
C A,B,C,D,E,F,G,H,I,J,K,I,Q,R,S,T,U,V,W,X,Y,Z,AA,BB,VV,CC,GG,
C         HH,SS, = ALL INTERNAL WORKING VARIABLES.
C AVGSOA = AVERAGE STOCK ON HAND AT REORDER
C BAKORD = TOTAL NUMBER OF BACKORDERS
C CHECK = DIGIT TO CAUSE NEW SETTIM VALUE TO BE READ
C DSEED = SEED FOR RANDOM NUMBER GENERATOR
C EOQA = COMPUTED EOQ AFTER SIMULATION RUN
C EOQQTY = ECONOMIC ORDER QUANTITY COMPUTED BEFORE SIMULATION
C          RUN
C EXPBO = EXPECTED NUMBER OF BACKORDERS THEORETICAL
C HOLCST = HOLDING COST PER ITEM PER YEAR
C HOLPER = HOLDING RATE PERCENTAGE (0<X<1)
C HITIME = TIME BETWEEN ARRIVALS TAKEN FROM ARRAY IR
C I = NUMBER OF REQUISITIONS
C INVLEV = INVENTORY LEVEL ACTUALLY ON-HAND
C INVPOS = INVENTORY POSITION (ON-HAND + ON-ORDER)
C IR = ARRAY OF POISSON GENERATED TIME BETWEEN ARRIVALS
C LEADTM = MEAN ORDER LEADTIME IN DAYS
C MAXA = COMPUTED MAXIMUM INVENTORY AFTER SIMULATION RUN
C MAXINV = MAXIMUM INVENTORY LEVEL
C NR = NUMBER OF ITEMS IN ARRAY IR
C OC = ARRAY THAT KEEPS TRACK OF THE NUMBER OF REQUISITIONS
C OL = ARRAY THAT KEEPS TRACK OF LEADTIMES FOR ORDERS
C ONORD = TOTAL AMOUNT ON ORDER AT ANY ONE TIME
C OQ = ARRAY THAT KEEPS TRACK OF ON ORDER QUANTITIES
C ORDCNT = TOTAL NUMBER OF ORDERS DURING THE SIMULATION
C ORDCST = ORDERING COST PER ORDER
C ORDYR = AVERAGE ORDERS PER YEAR
C RLAM = MEAN ARRIVAL RATE IN DAYS
C REQNYR = AVERAGE REQUISITIONS PER YEAR
C REORD = REORDER POINT
C REVCNT = COUNTS TOTAL NUMBER OF REVIEWS
C REVCST = COST PER REVIEW
C REVYR = AVERAGE REVIEWS PER YEAR
C REVTIM = CUMULATES TIME BETWEEN REVIEWS IN DAYS
```

```
C SAFSTK = SAFETY STOCK THEORETICAL
C SETTIM = THIS IS TOTAL TIME ALLOWED BETWEEN REVIEWS
C SHOCST = SHORTAGE COST PER SHORTAGE
C SIMRUN = TOTAL LENGTH OF SIMULATION RUN IN DAYS
C SMA = SUPPLY MANAGEMENT AVAILABILITY
C STKOA = TOTAL STOCK ON HAND AT ORDER ARRIVAL
C SOYR = AVERAGE STOCK-OUTS PER YEAR
C SUMLD = TOTAL LEADTIMES SUMMED FOR ALL ORDERS
C SUMORD = TOTAL NUMBER OF ORDERS
C TOTA = TOTAL YEARLY COST OF RUN WITH REVIEW CONSTRAINT
C TOTCO = TOTAL OPTIMAL COST BASED ON INITIAL INPUT VALUES
C TOTIME = KEEPS TRACK OF REAL TIME OF SIMULATION
C TOTSO = TOTAL NUMBER OF STOCK-OUTS ON RUN
C TVCO = TOTAL VARIABLE COST OPTIMAL
C TVCR = TOTAL VARIABLE COST SIMULATION RUN
C YEAR = FACTOR TO COMPUTE YEARLY COSTS
C
C DECLARE VARIABLES AND ARRAYS
C
  REAL TVCR,RVCO,REQNYR,REVYR,ORDYR,SOYR,YEAR,SAFSTK,EXPBO
  REAL HOLCST,PRICE,HOLPER,A,FLAM,ORDCST,SHOCST,B,EOQQTY
  REAL MAXINV,C,BAKORD,REORD,EOQA,MAXA,D,E,SMA,REVCST
  REAL TOTCO,Z,Y,X,W,V,U,TOTA,AA,BB,H,G,R,S,T,CC,GG,HH,SS
  REAL STKOA,AVGSOA
C
  INTEGER ONORD,J,K,I,SUMORD,SUMLD,NR,IER,SIMRUN,TOTIME
  INTEGER HITIME,SETTIM,REVTIM,INVLEV,TOTSO,INVPOS,ONORD
  INTEGER REVCNT,ORDCNT,LEADTM,CHECK,N
  INTEGER IR(2500),OC(100),OQ(100),OL(100)
C
  DOUBLE PRECISION DSEED
C
C INITIALIZE VARIABLES AND SET COST AND RUNTIME FIGURES.
C READ THE PERIOD OF FIXED REVIEW AND MAKE A CHECK FOR
C END OF DATA RUN
C
  READ(5,810)SETTIM,CHECK
C
C DSEED = 35110.0D0
10 HOLCST = 0.0
  EOQQTY = 0.0
  MAXINV = 0.0
  A = 0.0
  B = 0.0
  C = 0.0
  REORD = 77.0
  EXPBO = .034
  BAKORD = 0.0
  NR = 2500
  PRICE = 100.0
```

```
      HOLPER = .23
      ORDCST = 175.0
      SHOCST = 350.0
      RLAM = 1.0
      SIMRUN = 14600
      LEADTM = 57
      TOTIME = 0
      HITIME = 0
      REVTIM = 0
      SIMCNT = 0
      REVCNT = 0
      ORDCNT = 0
      SUMORD = 0
      SUMLD = 0
      ONORD = 0
      TOTSO = 0
      STKOA = 0.0
C
C ZERO ORDER ARRAYS
C
      DO 5 J=1,100
              OC(J)=0
              OQ(J)=0
              OL(J)=0
    5 CONTINUE
C
C
C BEGIN PREPROGRAM CALCULATIONS WITH THE CALCULATION
C OF THE ECONOMIC ORDER QUANTITY (EOQ).  DEMAND IN THIS
C CASE IS FIGURED BY DIVIDING DAYS IN THE YEAR BY THE
C MEAN ARRIVAL RATE (365.0/RLAM).
C
      HOLCST = (PRICE * HOLPER)
      A = 2.0 * (365.0/RLAM)
      B = (SHOCST * EXPBO) + ORDCST
      CC = (A * B)/HOLCST
      EOQQTY = SQRT(CC)
C
C THE MAXIMUM INVENTORY LEVEL IS COMPUTED BY ADDING THE EOQ
C QUANTITY TO THE REORDER POINT.  THE INITIAL INVENTORY LEVEL
C AND INVENTORY POSITION IS SET AT HALF THE EOQ QUANTITY PLUS
C THE REORDER POINT.  SAFETY STOCK IS COMPUTED BY
C SUBTRACTING DEMAND IN A LEADTIME FROM THE REORDER POINT.
C
      C = SQRT((SHOCST) / (HOLCST + SHOCST))
      MAXINV = EOQQTY + REORD
      INVLEV = IFIX(REORD) + IFIX(EOQQTY)/2
      INVPOS = INVLEV
      SAFSTK = REORD - (FLOAT(LEADTM)/RLAM)
C
C
```

```
C POISSON ARRIVALS ARE GENERATED USING THE NAVAL POSTGRADUATE
C SCHOOL'S IMSL SUBROUTINE GGPOS.  THIS SUBROUTINE MUST BE
C INVOKED IN IBM 3033 CMS BY USING THE STATEMENT
C "GLOBAL MACLIB IMSLDP" PRIOR TO THE RUNNING OF THE PROGRAM.
C
  CALL GGPOS(RLAM,DSEED,NR,IR,IER)
C
C BEGIN SIMULATION
C
          DO 50 I=1,2500
C
C CHECK TO SEE IF SIMULATION RUN TIME IS OVER, CUMULATE TIME
C BETWEEN REVIEWS
C
                  IF(TOTIME.GE.SIMRUN) GO TO 500
                  HITIME = IR(I)
                  TOTIME = TOTIME + HITIME
                  REVTIM = REVTIM + HITIME
C
C CHECK TO SEE IF SYSTEM IS OUT OF STOCK AND RECALCULATE
C INVENTORY LEVELS BASED ON NEW REQUISITION.
C
                  IF(INVLEV.GT.0) GO TO 300
                          TOTSO = TOTSO + 1
350               INVLEV = INVLEV - 1
                  INVPOS = INVLEV + ONORD
C
C CHECK TO SEE IF TIME BETWEEN REVIEWS IS FINISHED
C AND RESET THE TIME BETWEEN REVIEWS.
C
                  IF(SETTIM.GE.REVTIM) GO TO 400
                          REVTIM = 0
                          REVCNT = REVCNT + 1
C
C CHECK TO SEE IF INVENTORY POSITION IS BELOW THE
C THE REORDER POINT.  IF SO, CALL UP REORDER SUBROUTINE.
C
                          IF(INVPOS.GT.IFIX(REORD)) GO TO 400
                                  ORDCNT = ORDCNT + 1
C
C GENERATE A REORDER
C
  CALL ORDER(MAXINV,ONNORD,LEADTM,INVLEV,OC,OL,OQ,INVPOS)
C
C BEFORE GENERATING THE NEXT REQUISITION CALL UPDATE SUBROUTINE
C WHICH WILL UPDATE INVENTORY LEVELS AND ONORDER LEADTIMES
C
```

```
400 CALL UPDATE(ONORD,HITIME,SUMORD,INVLEV,SUMLD,OC,OL,OQ,
  1            INVPOS,ORDCNT,STKOA,AVGSOA)
  C
  C START A NEW REQUISITION INTO THE SYSTEM
  C
 50 CONTINUE
  C
  C COMPUTE FINAL STATISTICS AS YOU EXIT PROGRAM
  C
  C THIS SECTION COMPUTES THE ACTUAL EOQ QUANTITY, MAXIMUM
  C INVENTORY LEVEL, AND SUPPLY MANAGEMENT AVAILABILITY THAT
  C WOULD HAVE RESULTED FROM THIS SIMULATION
  C
500 YEAR = 365.0/FLOAT(SIMRUN)
    ORDYR = FLOAT(ORDCNT) * YEAR
    D = YEAR * FLOAT(I)
    E = FLOAT(TOTSO) * YEAR
    GG = E * (1.0/ORDYR)
    HH = (SHOCST * GG) + ORDCST
    SS = (2.0 * D * HH)/HOLCST
    EOQA = SQRT(SS)
    MAXA = EOQA + REORD
    SMA = (FLOAT(I) - FLOAT(TOTSO))/FLOAT(I)
  C
  C THIS SECTION COMPUTES THE TOTAL THEORETICAL COSTS OF THIS
  C SYSTEM BASED SOLELY ON THE INITIAL INPUT VALUES.  NOTE THAT
  C REVIEW COSTS WILL BE INCURRED ON EVERY REQUISITION
  C
    Z = (RLAM * 365.0) * PRICE
    Y = (ORDCST * (365.0/RLAM)) / EOQQTY
    X = HOLCST * ((EOQQTY/2.0) + SAFSTK + EXPBO)
    W = (365.0/RLAM) / EOQQTY
    V = SHOCST * EXPBO
    U = REVCST * (365.0/RLAM)
    VV = W * V
    TOTCO = Z+Y+X+U+VV
    TVCO = Y+X+VV
  C
  C THIS COMPUTES THE TOTAL YEARLY COSTS OF OPERATING THIS
  C SYSTEM BASED ON THE ACTUAL RESULTS OF THE SIMULATION.
  C
    T = PRICE * (365.0/FLOAT(SIMRUM)) * FLOAT(I)
    S = (ORDCST*FLOAT(ORDCNT))*(365.0/FLOAT(SIMRUN))
    R = REORD - (FLOAT(LEADTM)/365.0) * (FLOAT(I) * YEAR)
    Q = (EOQA/2.0) + R + E
    G = HOLCST * Q
    AA = FLOAT(TOTSO)*SHOCST*(365.0/FLOAT(SIMRUN)
    BB = (FLOAT(REVCNT)*REVCST)*(365.0/FLOAT(SIMRUM))
    TOTA = T+S+G+AA+BB
    TVCR = S+G+AA
```

```
   C
   C THIS SECTION COMPUTES SUMMARY STATISTICS FOR THE
   C SIMULATION RUN
   C
     REQNYR = FLOAT(I) * YEAR
     ORDYR = FLOAT(ORDCNT) * YEAR
     SOYR = FLOAT(TOTSO) * YEAR
     REVYR = FLOAT(REVCNT) * YEAR
   C
   C THESE STATEMENTS WRITE THE SUMMARY STATISTICS
   C
     WRITE(6,380)SETTIM
     WRITE(6,600)
     WRITE(6,700)EOQQTY,MAXINV,Z,Y,X,VV,U,TOTCO,TVCO,AVGSOAV
     WRITE(6,800)
     WRITE(6,900)EOQA,MAXA,T,S,G,AA,BB,TOTA,TVCR,SMA
     WRITE(6,300)
     WRITE(6,250)I,HITIME,TOTIME,REVTIM,REVCNT,INVLEV,
   1             INVPOS,ORDCNT,SUMORD,ONORD,SUMLD,TOTSO
     WRITE(6,305)
     WRITE(6,375)REQNYR,REVYR,ORDYR,SOYR,SETTIM,LEADTM,
   1             PRICE,REVCST,ORDCST,CHOCST,RLAM,SIMRUN
   C
   C THIS SECTION FORMATS THE READ AND WRITE STATEMENTS
   C
380  FORMAT(1X,"RUN WITH TIME BETWEEN REVIEWS SET AT: "I6,//)
250  FORMAT(12I7,/)
300  FORMAT(2X,'REQN',1x,'HITIME',1X,'TOTIME',1X,'REVTIM',
   1       1X,'REVCNT',1X,'INVLEV',1X,'INVPOS',1X,'ORDCNT',
   1       1X,'SUMORD'1X,'ONORD',1X,'SUMLD',1X,'TOTSO')
600  FORMAT(1X,'THEORETICAL"',2X,'EOQQTY',5X,"MAXINV',5X,
   1       'ITCOST',5X,'ORDCST',5X,'HOLCST',5X,'SHOCST',5X,
           'REVCST',5X,'TOTCST',5X,'  TVC ',5X,'AVGSOA')
700  FORMAT(12X,10F11.2,/)
800  FORMAT(1X,'SIMULATION : ',2X,'EOQQTY',5X,'MAXINV',5X,
   1       'ITCOST',5X,'ORDCST',5X,'HOLCST',5X,'SHOCST',
   1       5X,'REVCST',5X,'TOTCST',5X,'  TVC ',5X,'  SMA ')
900  FORMAT(12X,9F11.2,F11.4,/)
810  FORMAT(2I5)
305  FORMAT(5X,'REQNYR',5X,' REVYR',5X,' ORDYR',5X,' SOYR ',
   1       6X,'SET',7X,'LEADTM',5X,'PRICE',5X,'REVCST',5X,
   1       'ORDCST',5X,'SHOCST',5X,' RLAM ',5X,'SIMRUN')
375  FORMAT(4F11.2,2I11,5F11.2,I11,//)
255  FORMAT(1X,'MAC INVENTORY: ',F8.2,3X,'REORDER POINT" ',
   1       F8.2,3X,'SAFETY STOCK: ',F8.2,3X,'EXPECTED B/o: ',
   1       F8.4,3X,'GENERATED B/O: ',F8.4,/)
   C
   C READ IN A NEW TIME BETWEEN REVIEWS AND CHECK DIGIT
   C
     READ(5,810)SETTIM CHECK
     IF(CHECK.GT.0) GO TO 10
```

```
      DSEED = DSSED + 112.0D0
C
C
      STOP
      END
C
C END OF PROGRAM
C
C BEGINNING OF SUBROUTINE SECTION
C
C THIS SUBROUTINE COMPUTES A NEW ORDER.  THE QUANTITY ORDER-
  ED WILL BE THE DIFFERENCE BETWEEN THE INVENTORY POSITION
  AND THE MAXIMUM INVENTORY LEVEL
C
      SUBROUTINE ORDER(MAXINV,ONORD,LEADTM,INVLEV,OC,OL,OQ,INVPOS)
              INTEGER OC(100),OL(100),OQ(100)
              INTEGER INVLEV,ONORD,LEADTM,INVPOS
              REAL MAXINV
              DO 60 J=1,50
                      IF(OC(J).EQ.0) GO TO 65
60            CONTINUE
              GO TO 68
65            K=J
              OC(K)=1
              OQ(K)=(IFIX)MAXINV-INVLEV-ONORD
              OL(K)=LEADTM
68    RETURN
      END
C
C THIS ROUTINE UPDATES LEADTIMES AND ADDS TO INVENTORY LEVEL
C AN ONORDER QUANTITY IF IT IS TIME FOR THE ORDER TO COME IN.
C IT ALSO SUMS THE REQUISITIONS OUTSTANDING, THEIR QUANTITIES
C AND LEADTIMES
C
      SUBROUTINE UPDT(ONORD,HITIME,SUMORD,INVLEV,SUMLD,OC,OL,
     1                OQ,INVPOS,ORDCNT,STKOA,AVGSOA)
              INTEGER ONORD,HITIME,SUMORD,INVLEV,SUMLD
              INTEGER INVPOS,N,ORDCNT
              INTEGER OC(100),OL(100),OQ(100)
              REAL STKOA,AVGSOA
              DO 80 J=50
                      IF(OC(J).EQ.1) OL(J)=OL(J)-HITIME
80            CONTINUE
              N=51
C
              CO 70 J=1,50
                      IF(OC(J).GE.1.AND.OL(J).LE.HITIME) N=J
70            CONTINUE
```

```
          IF(OQ(N).LE.0) GO TO 73
                  STKOA = STKOA + FLOAT(INVLEV)
                  AVGSOA = STKOA/FLOAT(ORDCNT)
                  INVLEV=INVLEV+OQ(N)
                  OC(N)=0
                  OQ(N)=0
                  OL(N)=0
C
          ONORD=0
          SUMQTY=0
          SUMLDq0
          DO 90 J=1,50
                  K=J
                  ONORD=ONORD+OQ(K)
                  SUMORD=SUMORD+OC(K)
                  SUMLD=SUMLD+OL(K)
90        CONTINUE
          INVPOS=INVLEV+ONORD
  RETURN
  END
C
C THE FOLLOWING EXAMPLE DATA ENTRY IS THE TIME BETWEEN
C REVIEWS AND A CHECK DIGIT FOR END OF RUN.  TO STOP
C INPUTING VALUES ARE A CHECK DIGIT OF ZERO
C
$ENTRY
  0 1
  3 1
  7 1
 14 1
 30 1
 90 1
180 1
180 0
```

APPENDIX B

FIXED PERIOD REVIEW MODEL SIMULATION PROGRAM

```
$JOB
C
C THIS PROGRAM IS A SIMULATION OF A THEORETICAL INVENTORY
C SYSTEM WHERE A FIXED PERIOD REVIEW MODEL IS USED BASED
C ON AN OPTIMAL TIME BETWEEN REVIEWS.  THIS OPTIMAL TIME
C BETWEEN REVIEWS CAN BE OPTIONALLY CHANGED BY A PERCENTAGE
C FACTOR TO DETERMINE THE CORSTS OF OPERATING THE SYSTEM
C IN A NON-OPTIMAL MANNER.  THE PROGRAM IS WRITTEN IN THE
C FORTRAN PROGRAMMING LANGUAGE USING THE WATFIV COMPILER
C
C THE FOLLOWING IS A DESCRIPTION OF THE VARIABLES WITHIN THE
C PROGRAM
C
C A,B,C,D,E,F,G,H,I,J,K,I,Q,R,S,T,U,V,W,X,Y,Z,AA,BB,VV,CC,GG,
          HH,SS, = ALL INTERNAL WORKING VARIABLES.
C AVGREQ = AVERAGE REORDER POINT DURING SIMULATION RUN
C AVGSOA = AVERAGE STOCK ON HAND AT ORDER ARRIVAL
C RAKORD = TOTAL NUMBER OF BACKORDERS.
C CHANGE = % CHANGE OF REVIEW PERIOD FROM TOPT
C CHECK = DIGIT TO CAUSE NEW SETTIM VALUE TO BE READ
C CYCDM = UNITS DEMANDED IN A REVIEW CYCLE
C DEMAND = YEARLY THEORETICAL DEMAND
C DSEED = SEED FOR RANDOM NUMBER GENERATOR
C EOQA = COMPUTED EOQ AFTER SIMULATION RUN
C EOQQTY = ECONOMIC ORDER QUANTITY COMPUTER BEFORE SIMULATION
C          RUN
C EXPBO = EXPECTED NUMBER OF BACKORDERS THOERETICAL
C HOLCST = HOLDING COST PER ITEM PER YEAR
C HOLPER = HOLDING RATE PERCENTAGE (0<X<1)
C HITIME = TIME BETWEEN ARRIVALS TAKEN FROM ARRAY IR
C I = NUMBER OF REQUISITIONS
C INVLEV = INVENTORY LEVEL ACTUALLY ON-HAND
C INVPOS = INVENTORY POSITION (ON-HAND + ON-ORDER)
C IR = ARRAY OF POISSON GENERATED TIME BETWEEN ARRIVALS
C LEADCY = LEADTIME OF REVIEW CYCLE IN DAYS
C LEADDM = UNITS DEMANDED IN AN ORDER LEADTIME
C LEADTM = MEAN ORDER LEADTIME IN DAYS
C MAXA = COMPUTED MAXIMUM INVENTORY AFTER SIMULATION RUN
C MAXINV = MAXIMUM INVENTORY LEVEL
C NR = NUMBER OF ITEMS IN ARRAY IR
C OC = ARRAY THAT KEEPS TRACK OF THE NUMBER OF REQUISITIONS
C OL = ARRAY THAT KEEPS TRACK OF LEADTIMES FOR ORDERS
C ONORD = TOTAL AMOUNT ON ORDER AT ANY ONE TIME
C OQ = ARRAY THAT KEEPS TRACK OF ON ORDER QUANTITIES
C ORDCNT = TOTAL NUMBER OF ORDERS DURING THE SIMULATION
C ORDCST = ORDERING COST PER ORDER
```

```
C ORDYR = AVERAGE ORDERS PER YEAR
C PRICE = ITEM PRICE PER UNIT
C RLAM = MEAN ARRIVAL RATE IN DAYS
C REQNYR = AVERAGE REQUISITIONS PER YEAR
C REORD = REORDER POINT
C REVCNT = COUNTS TOTAL NUMBER OF REVIEWS
C REVCST = COST PER REVIEW
C REVYR = AVERAGE REVIEWS PER YEAR
C REVTIM = CUMULATES TIME BETWEEN REVIEWS IN DAYS
C SAFSTK = SAFETY STOCK THEORETICAL
C SETTIM = THIS IS TOTAL TIME ALLOWED BETWEEN REVIEWS
C SHOCST = SHORTAGE COST PER SHORTAGE
C SIMRUN = TOTAL LENGTH OF SIMULATION RUN IN DAYS
C SMA = SUPPLY MANAGEMENT AVAILABILITY
C SOYR = AVERAGE STOCK-OUTS PER YEAR
C SUMLD = TOTAL LEADTIMES SUMMED FOR ALL ORDERS
C SUMORD = TOTAL NUMBER OF ORDERS
C TOLEAD = LEADTIME DAYS - REVIEW AND ORDER CYCLE
C THRVYR = THEORETICAL REVIEWS PER YEAR
C TOPT = OPTIMAL TIME BETWEEN REVIEWS IN A YEAR
C TOPTC = OPTIMAL TIME BETWEEN REVIEWS CHANGED BY % FACTOR
C TOTA = TOTAL YEARLY COST OF RUN WITH REVIEW CONSTRAINT
C TOTCO = TOTAL OPTIMAL COST BASED ON INITIAL INPUT VALUES
C TOTIME = KEEPS TRACK OF REAL TIME OF SIMULATION
C TOTSO = TOTAL NUMBER OF STOCK-OUTS ON RUN
C TOTUTS = TOTAL UNITS DEMANDED IN A LEADTIME
C TVCO = TOTAL VARIABLE COST OPTIMAL
C TVCR = TOTAL VARIABLE COST SIMULATION RUN
C YEAR = FACTOR TO COMPUTE YEARLY COSTS
C
C DELCARE VARIABLES AND ARRAYS
C
  REAL TVCR,TVCO,REQNYR,REVYR,ORDYR,SOYR,YEAR,SAFSTK,EXPBO
  REAL HOLCST,PRICE,HOLPER,A,RLAM,ORDCST,SHOCST,B,EOQQTY
  REAL MAXINV,C,BAKORD,REORD,EOQA,MAXA,D,E,SMA,REVCST
  REAL TOTCO,Z,Y,X,W,V,U,TOTA,AA,BB,H,G,R,S,T,CC,GG,HH,SS
  REAL DEMAND,TOPT,TOPTC,THRVYR,CYCDM,LEADDM,TOTUTS,AVGREQ
  REAL STKOA,AVGSOA
C
  INTEGER ONORD,J,K,I,SUMORD,SUMLD,NR,IER,SIMRUN,TOTIME
  INTEGER HITIME,SETTIM,REVTIM,INVLEV,TOTSO,INVPOS,CHECK
  INTEGER REVCNT,ORDCNT,LEADTM,LEADCY,TOLEAD,N
  INTEGER IR(2500),OC(100),OQ(100),OL(100)
C
  DOUBLE PRECISION DSEED
C
C INITIALIZE VARIABLES AND SET COST AND RUNTIME FIGURES.
C EXPECTED BACKORDERS AND MAXIMUM INVENTORY ARE DETERMINED
C SEPARATELY USING AN ITERATIVE PROCEDURE BASED ON THE
C PROBABILITY OF A STOCK-OUT, AND DEMAND IN A CYCLE AND
C LEADTIME WITHIN A POISSON DISTRIBUTION
```

```
C
      DSEED = 79984.0D0
      CHANGE = 1.0
C
   10 MAXINV = 52.0
      EXPBO = .0112
      DSEED = 29146.0
      NR = 2500
      PRICE = 100.0
      HOLPER = .23
      HOLCST = HOLPER * PRICE
      ORDCST = 175.0
      SHOCST = 350.0
      REVCST = 5.00
      RLAM = 1.0
      SIMRUN = 3650
      DEMAND = 365.0/RLAM
      LEADTM = 82
C
C THE FOLLOWING DETERMINES THE OPTIMAL TIME BETWEEN REVIEWS,
C THE REVIEWS PER YEAR, AND THE DAYS IN A CYCLE.
C
      TOPT = SQRT((2.0 * ORDCST)/(DEMAND * HOLCST))
      TOPTC = TOPT * CHANGE
      THRVYR = 1.0/TOPTC
      LEADCY = IFIX(TOPTC * 365.0)
      SETTIM = IFIX(TOPTC * 365.0)
      REORD = 0.0
      TOTIME = 0
      REVTIM = 0
      REVCNT = 0
      ORDCNT = 0
      SUMORD = 0
      SUMLD = 0
      ONORD = 0
      STKOA = 0.0
      TOTSO = 0
C
C ZERO ORDER ARRAYS
C
      DD 5 J=1,100
              OC(J)=0
              OQ(J)=0
              OL(J)=0
    5 CONTINUE
C
C
C BEGIN PREPROGRAM CALCULATIONS WITH THE CALCULATION
C OF THE ECONOMIC ORDER QUANTITY (EOQ).  DEMAND IN THIS
C CASE IS FIGURED BY DIVIDING DAYS IN THE YEAR BY THE
C MEAN ARRIVAL RATE (365.0/RLAM).
```

```
C
      A = 2.0 * (365.0/RLAM)
      B = (SHOCST * EXPBO) + ORDCST
      CC = (A * B)/HOLCST
      EOQQTY = SQRT(CCO
C
C THE NUMBER OF UNITS DEMANDED IN A CYCLE AND LEADTIME
C ARE COMPUTED HERE.  INVENTORY LEVEL IS SET AT THE MAXIMUM
C INVENTORY LEVEL.  SAFETY STOCK IS DETERMINED BY SUBTRACTING
C DEMAND IN A CYCLE AND A LEADTIME FROM THE MAXIMUM INVENTORY
C LEVEL.
C
      CYCDM = FLOAT(LEADCY)/RLAM
      LEADDM = FLOAT(LEADTM)/RLAM
      TOTUTS = CYCDM + LEADDM
      INVLEV = IFIX(MAXINV)
      INVPOS = INVLEV
      SAFSTK = MAXINV - TOTUTS
C
C POISSON ARRIVALS ARE GENERATED USING THE NAVAL POSTGRADUATE
C SCHOOL'S IMSL SUBROUTINE GGPOS.  THIS SUBROUTINE MUST BE
C INVOKED IN IBM 3033 CMS BY USING THE STATEMENT
C "GLOBAL MACLIB IMSLDP" PRIOR TO THE RUNNING OF THE PROGRAM.
C
      CALL GGPOS(RLAM,DSEED,NR,IR,IER)
C
C BEGIN SIMULATION
C
              CO 50 I=1,2500
C
C CHECK TO SEE IF SIMULATION RUN TIME IS OVER, CUMULATE TIME
C BETWEEN REVIEWS
                      IF(TOTIME.GE.SIMRUN) GO TO 500
                      HITIME = IR(I)
                      TOTIME = TOTIME + HITIME
                      REVTIM = REVTIM + HITIME
C
C CHECK TO SEE IF SYSTEM IS OUT OF STOCK AND RECALCULATE
C INVENTORY LEVELS BASED ON NEW REQUISITION
C
                      IF(INVLEV.GT.0) GO TO 350
                              TOTSO = TOTSO + 1
350                   INVLEV = INVLEV - 1
                      INVPOS = INVLEV + ONORD
C
C CHECK TO SEE IF TIME BETWEEN REVIEWS IS FINISHED
C AND RESET THE TIME BETWEEN REVIEWS AND ORDER TO
C MAXIMUM INVENTORY LEVEL.  DETERMINE THE AVERAGE
C LEVEL OF INVENTORY AT THE ORDER.
C
```

```
                   IF(SETTIM.GE.REVTIM) GO TO 400
                           REVTIM = 0
                           REVCNT = REVCNT + 1
                           ORDCNT = ORDCNT + 1
                           REORD = REORD + FLOAT(INVLEV)
                           AVGREQ = REORD/FLOAT(REVCNT)
C
C GENERATE A NEW ORDER
C
  CALL ORDER(MAXINV,ONORD,LEADTM,INVLEV,OC,OL,OQ)
C
C BEFORE GENERATING THE NEXT REQUISITION CALL UPDATE SUBROUTINE
C WHICH WILL UPDATE INVENTORY LEVELS AND ONORDER LEADTIMES
C
400 CALL UPDATE(ONORD,HITIME,SUMORD,INVLEV,SUMLD,OC,OL,OQ,
1               INVPOS,ORDCNT,STKOA,AVGSOA)
C
C START A NEW REQUISITION INTO THE SYSTEM
C
 50 CONTINUE
C
C COMPUTE FINAL STATISTICS AS YOU EXIT PROGRAM
C
C THIS SECTION COMPUTES THE ACTUAL EOQ QUANTITY, MAXIMUM
C INVENTORY LEVEL, AND SUPPLY MANAGEMENT AVAILABILITY THAT
C WOULD HAVE RESULTED FROM THIS SIMULATION
C
500 YEAR = 365.0/FLOAT(SIMRUN)
  ORDYR = FLOAT(ORDCNT) * YEAR
  D = YEAR * FLOAT(I)
  E = FLOAT(TOTSO) * YEAR
  GG = E * (1.0/ORDYR)
  HH = (SHOCST * GG) + ORDCST
  SS = (2.0 * D * HH)/HOLCST
  EOQA = SQRT(SS)
  MAXA = MAXINV
  SMA = (FLOAT(I) - FLOAT(TOTSO))/FLOAT(I)
C
C THIS SECTION COMPUTES THE TOTAL THEORETICAL COSTS OF THIS
C SYSTEM BASED SOLELY ON THE INITIAL INPUT VALUES.  NOTE THAT
C REVIEW COSTS WILL BE INCURRED ON EVERY REQUISITION
C
  Z = (365.0/RLAM) * PRICE
  Y = (1.0/TOPTC) * ORDCST
  W = ((DEMAND * TOPTC)/2.0) + (DEMAND * (FLOAT(LEADTM)/365.0))
  X = HOLCST * (MAXINV - W)
  V = (1.0/TOPTC) * SHOCST * EXPBO
  U = (1.0/TOPTC) * REVCST
  TOTCO = Z+Y+X+U+V
  TVCO = Y+X+V
```

```
C
C THIS SECTION COMPUTES THE TOTAL YEARLY COSTS OF OPERATING
C THIS SYSTEM BASED ON THE ACTUAL RESULTS OF THE SIMULATION.
C
  T = PRICE * (365.0/FLOAT(SIMRUN) * FLOAT(I)
  S = (ORDCST*FLOAT(ORDCNT))*(365.0/FLOAT(SIMRUN))
  R = (YEAR * FLOAT(I) * TOPTC)/2
  Q = (YEAR * FLOAT(I)) * (FLOAT(LEADTM)/365.0)
  G = HOLCST * (MAXINV - (R + Q))
  AA = FLOAT(TOTSO)*SHOCST*(365.0/FLOAT(SIMRUN))
  BB = (FLOAT(REVCNT)*REVCST)*(365.0/FLOAT(SIMRUN))
  TOTA = T+S+G+AA+BB
  TVCR = S+G+AA
  YEAR = 365.0/FLOAT(SIMRUN)
C
C THIS SECTION COMPUTES SUMMARY STATISTICS FOR THE
C SIMULATION RUN
C
  REQNYR = FLOAT(I) * YEAR
  SOYR = FLOAT(TOTSO) * YEAR
  REVYR = FLOAT(REVCNT) * YEAR
C
C THESE STATEMENTS WRITE THE SUMMARY STATISTICS
C
  WRITE(6,380)SETTIM
  WRITE(6,600)
  WRITE(6,700)EOQQTY,MAXINV,Z,Y,X,V,Y,TOTCO,TVCO,AVGSOA
  WRITE(6,800)
  WRITE(6,900)EOQA,MAXA,T,S,G,AA,BB,TOTA,TVCR,SMA
  WRITE(6,300)
  WRITE(6,250)I,HITIME,TOTIME,REVTIM,REVCNT,INVLEV,
1             INVPOS,ORDCNT,SUMORD,ONORD,SUMLD,TOTSO
  WRITE(6,255)MAXINV,AVGREQ,SAFSTK,EXPBO,GG
  WRITE(6,310)CYCDM,LEADDM,THRVYR
  WRITE(6,305)
  WRITE(6,375)REQNRY,REVYR,ORDYR,SOYR,SETTIM,LEADTM,
1             PRICE,REVCST,ORDCST,SHOCST,RLAM,SIMRUN
C
C THIS SECTION FORMATS THE READ AND WRITE STATEMENTS
C
  380 FORMAT(1X,"RUN WITH TIME BETWEEN REVIEWS SET AT: "I6,//)
  250 FORMAT(12I7,/)
  300 FORMAT(2X,'REQN',1x,'HITIME',1X,'TOTIME',1X,'REVTIM',
1            1X,'REVCNT',1X,'INVLEV',1X,'INVPOS',1X,'ORDCNT',
1            1X,'SUMORD',1X,'ONORD',1X,'SUMLD',1X,'TOTSO')
600 FORMAT(1X,'THEORETICAL:',2X,'EOQQTY',5X,'MAXINV',5X,
1 'ITCOST',5X,'ORDCST',5X,'HOLCST',5X,'SHOCST',5X,
  'REVCST',5X,'TOTCST',5X,'  TVC ',TX,'AVGSOA')
700 FORMAT(12X,10F11.2,/)
```

```
800 FORMAT(1X,'SIMULATION : ',2X,'EOQQTY',5X,'MAXINV',5X,
  1        'ITCOST',5X,'ORDCST',5X,'HOLCST',5X,'SHOCST',
  1        5X,'REVCST',5X,'TOTCST',5X,'  TVC ',5X,'  SMA ')
900 FORMAT(12X,9F11.2,F11.4,/)
810 FORMAT(F5.2,I5)
305 FORMAT(5X,'REQNYR',5X,' REVYR',5X,; ORDYR',5X,' SOYR ',
  1        6X,'SET',7X,'LEADTM',5X,'PRICE',5X,'REVCST',5X,
  1        'ORDCST',5X,'SHOCST',5X,' RLAM ',5X,'SIMRUN')
375 FORMAT(4F11.2,2I11,5F11.2,I11,//)
255 FORMAT(1X,'MAX INVENTORY: ',F8.2,3X,'AVG REORDER: ',
  1        F8.2,3X,'SAFETY STOCK: ',F8.2,3X,'EXPECTED B/O: ',
  1        F8.4,3X,'GENERATED B/O: ',F8.4,/)
310 FORMAT(1X,'CYCLE DEMAND: ',F6.1,2X,'LEADTIME DEMANDS: ',
  1        F6.1,2X,'THEORETICAL REVIEWS: ',F6.1,/)
  C
  C READ IN THE PERCENTAGE CHANGE IN TIME BETWEEN REVIEWS
  C AND A CHECK DIGIT FOR END OF RUN
  C
    READ(5,810) CHANGE, CHECK
    IF(CHECK.GT.0) GO TO 10
    DSEED = DSEED + 233.2D0
  C
  C
    STOP
    END
  C
  C END OF PROGRAM
  C
  C BEGINNING OF SUBROUTINE SECTION
  C
  C THIS SUBROUTINE COMPUTES A NEW ORDER.  THE QUANTITY ORDER-
    ED WILL BE THE DIFFERENCE BETWEEN THE INVENTORY POSITION
    AND THE MAXIMUM INVENTORY LEVEL
  C
    SUBROUTINE ORDER(MAXINV,ONORD,LEADTM,INVLEV,OC,OL,OQ)
            INTEGER OC(100),OL(100),OQ(100)
            INTEGER INVLEV,ONORD,LEADTM
            REAL MAXINV
            DO 60 J=1,50
                    IF(OC(J).EQ.0) GO TO 65
 60         CONTINUE
            GO TO 68
 65         K=J
            OC(K)=1
            OQ(K)=(IFIX)MAXINV-INVLEV-ONORD
            OL(K)=LEADTM
 68 RETURN
    END
```

```
C
C THIS ROUTINE UPDATES LEADTIMES AND ADDS TO INVENTORY LEVEL
C AN ONORDER QUANTITY IF IT IS TIME FOR THE ORDER TO COME IN.
C IT ALSO SUMS THE REQUISITIONS OUTSTANDING, THEIR QUANTITIES
C AND LEADTIMES
C
  SUBROUTINE UPDT(ONORD,HITIME,SUMORD,INVLEV,SUMLD,OC,OL,
1                 OG,INVPOS,ORDCNT,STKOA,AVGSOA)
          INTEGER ONORD,HITIME,SUMORD,INVLEV,SUMLD
          INTEGER INVPOS,N
          REAL STKOA,AVGSOA
          INTEGER OC(100),OL(100),OQ(100)
          DO 80 J=50
                  IF(OC(J).EQ.1) OL(J)=OL(J)-HITIME
80        CONTINUE
          N=51
C
          DO 70 J=1,50
                  IF(OC(J).GE.1.AND.OL(J).LE.HITIME) N=J
70        CONTINUE
          IF(OQ(N).LE.O) GO TO 73
                  AVGSOA = STKOA/FLOAT(ORDCNT)
73                INVLEV=INVLEV+OQ(N)
                  OC(N)=0
                  OQ(N)=0
                  OL(N)=0
C
          ONORD=0
          SUMQTY=0
          SUMLD=0
          DO 90 J=1,50
                  K=J
                  ONORD=ONORD+OQ(K)
                  SUMORD=SUMORD+OC(K)
                  SUMLD=SUMLD+OL(K)
90        CONTINUE
          INVPOS=INVLEV+ONORD
  RETURN
  END
C
C THIS IS WHERE THE INPUTED CHANGE FROM THE OPTIMAL TIME
C BETWEEN REVIEWS IS ENTERED.  USE ZERO TO TERMINATE THE RUNS
C IN THE CHECK FIGURE
C
$ENTRY
  .75  1
  .50  1
  .25  1
 1.25  1
 1.50  1
 1.75  1
```

```
 2.00  1
 1.00  0
C
C END OF DATA
C
```

APPENDIX C

POISSON PROBABILITY DISTRIBUTION PROGRAM

```
C
C THIS PROGRAM PRODUCES A POISSON PROBABILITY DISTRIBUTION
C BASED ON A DEMAND IN A LEADTIME, OR DEMAND IN A LEADTIME
C PLUS AND ORDER CYCLE.  THE CUMULATIVE DISTRIBUTION
C FUNCTION (CDF) AND THE COMPLEMENTARY CUMULATIVE DISTRI-
C BUTION (CCDF) ARE ALSO PRODUCED.
C
$JOB
C
C DECLARE VARIABLES
C
  REAL LEADTM,PROB,CDF,CCDF,CCCDF
  INTEGER N
C
C INPUT LEADTIME AND CHECK FOR END OF FILE
C
1 PRINT,' '
  PRINT,' '
  PRINT,'PROVIDE NEW LEADTIME:'
  READ,LEADTM
  IF(LEADTM.LT.0.0) STOP
C
C CONPUTE THE POISSON PROBABILITIES
C
  N = 0
  PROB = EXP(-LEADTM)
  CDF = PROB
  CCDF = 1.0 - PROB
  CCCDF = 1.0
C
C PRINT TITLES FOR DISTRIBUTION AND WRITE PROBABILITIES
C
  PRINT,' '
  PRINT,'  N        PROB          CDF P(X <=N)
1       CCDF P(X > N)       CCDF P(X >=N)
  PRINT,' '
  IF (PROB.GE.0.00001) WRITE (6,10) N,PROB,CDF,CCDF,CCCDF
  N = 1
C
C CREATE DISTRIBUTIONS
5 IF(FLOAT(N).LE.LEADTM) THEN DO
          PROB = PROB * M/FLOAT(N)
          CCCDF = 1.0 - CDF
          CDF = CDF + PROB
          CCDF = 1.0 - CDF
          IF(PROB.GE.0.00001) WRITE(6,10) N,PROB,CDF,
                                      CCDF,CCCDF
```

```
 1          N = N + 1
   ELSE DO
            PROB = PROB * LEADTM/FLOAT(N)
            IF(PROB.LT.0.00001) GO TO 1
            CCCDF = 1.0 - CDF
            CDF = CDF + PROB
            CCDF = 1.0 - CDF
            WRITE(6,10)N,PROB,CDF,CCDF,CCCDF
            N = N + 1
   END IF
   GO TO 5
 C
 C FORMAT STATEMENT
 C
10 FORMAT(1X,I3,5X,F10.4,F15.4,F19.4,F22.4)
   END
 $ENTRY
```

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A methodology for
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